Search of DM annihilation in Galactic Stellar Streams with the Fermi LAT

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Fermi Gamma-ray Space Telescope

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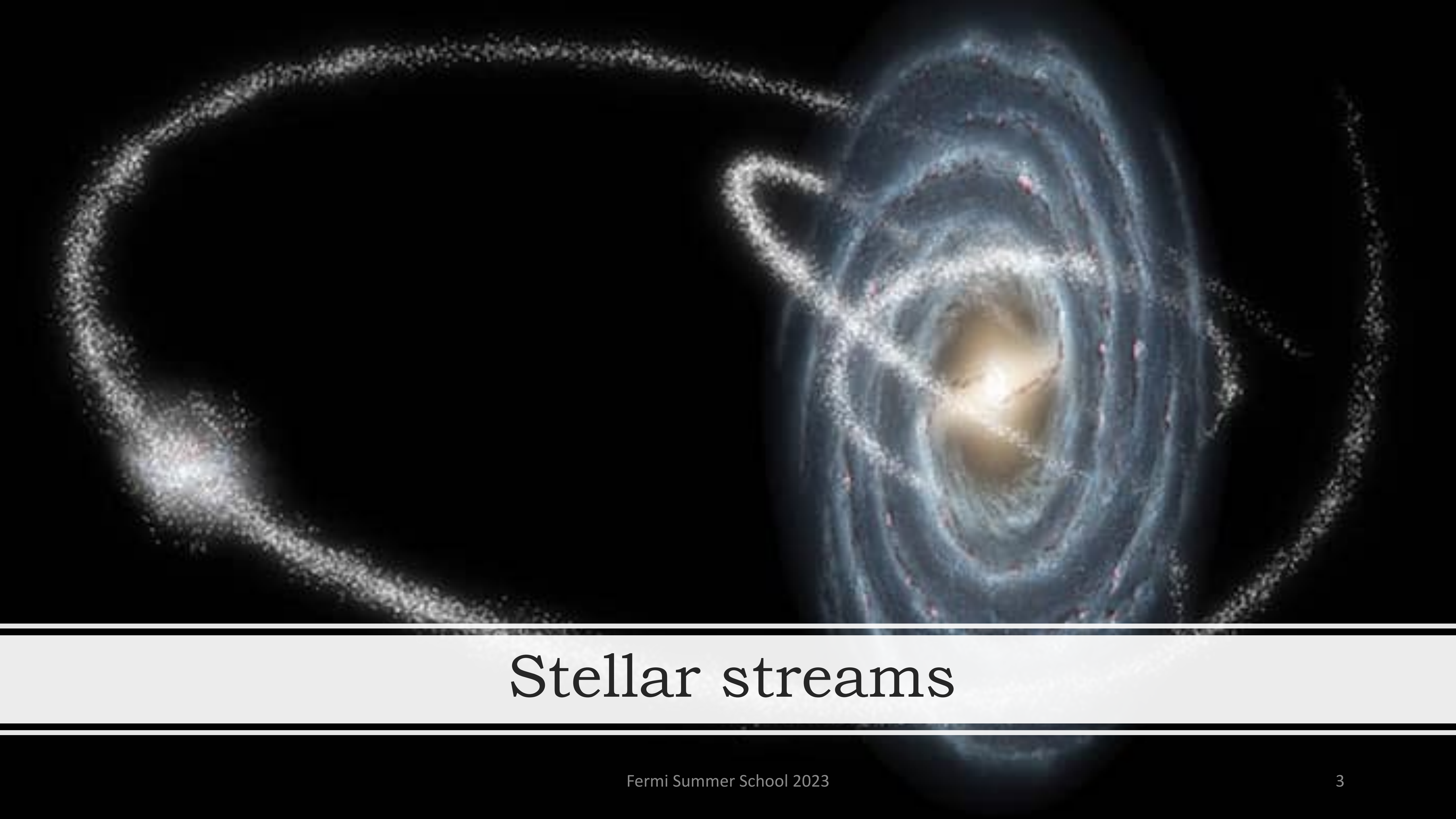
Motivation

Different strategies for dark matter (DM) searches.

Gamma rays as the *golden channel* for DM indirect searches, with many astrophysical targets already scrutinized (galactic center, dwarf spheroidal galaxies, galaxy clusters, …).

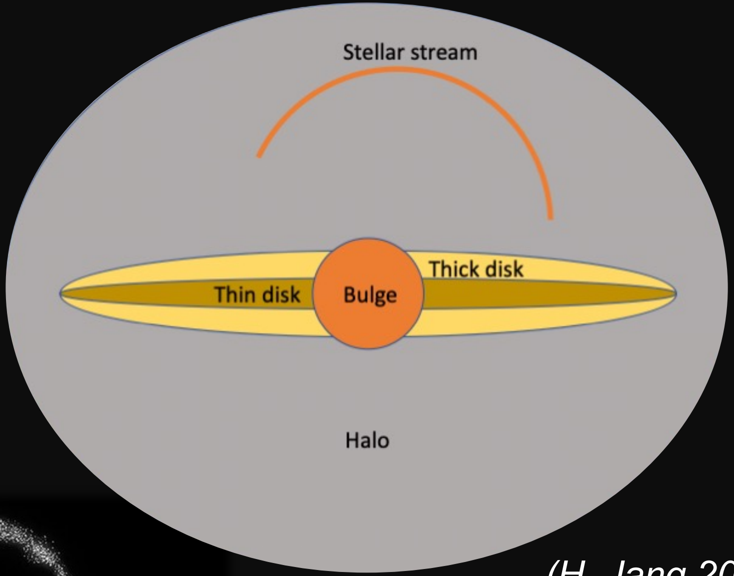
Stellar streams as a ***new target*** for DM indirect searches with gamma rays.



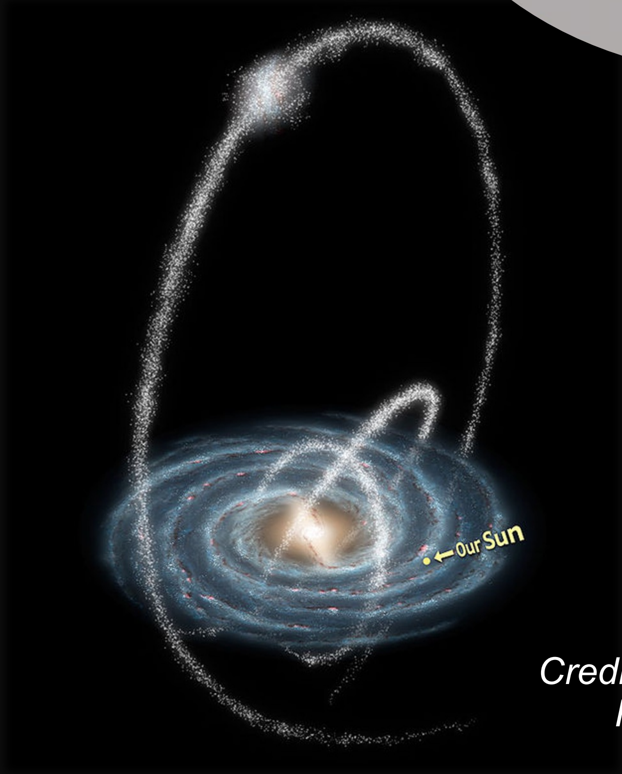
Stellar streams

What are stellar streams?

- Narrow tubular galactic structures made of stars, orbiting a galaxy, remnants of ancient globular clusters or dwarf galaxies heavily stripped in the tidal field of the galaxy.
- Extended structures, with lengths from 1 kpc to more than 50 kpc.
- Range in heliocentric distance from a few kpc to 100 kpc.

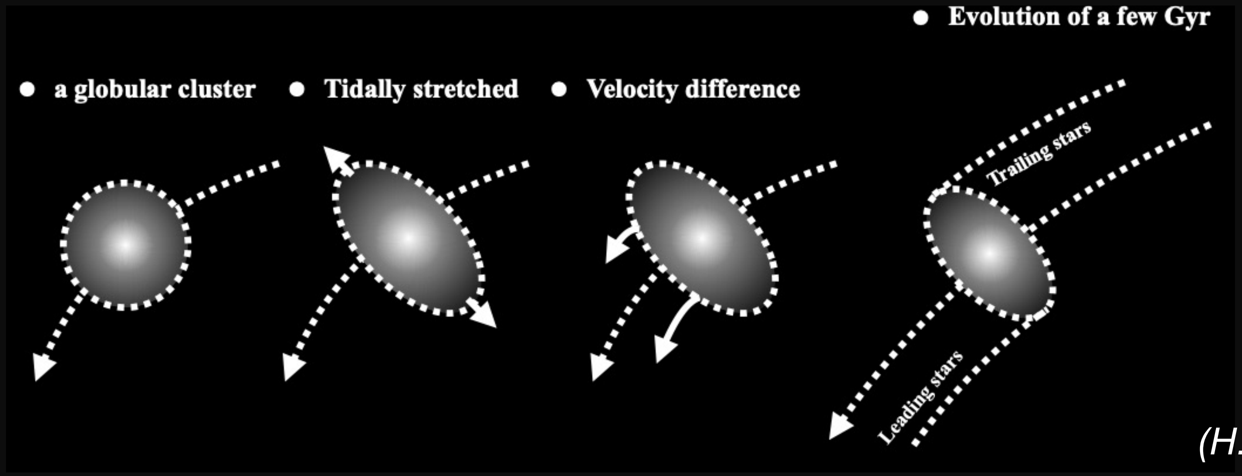


(H. Jang 2021)



Credit: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

How do stellar streams originated?



(H. Jang 2021)

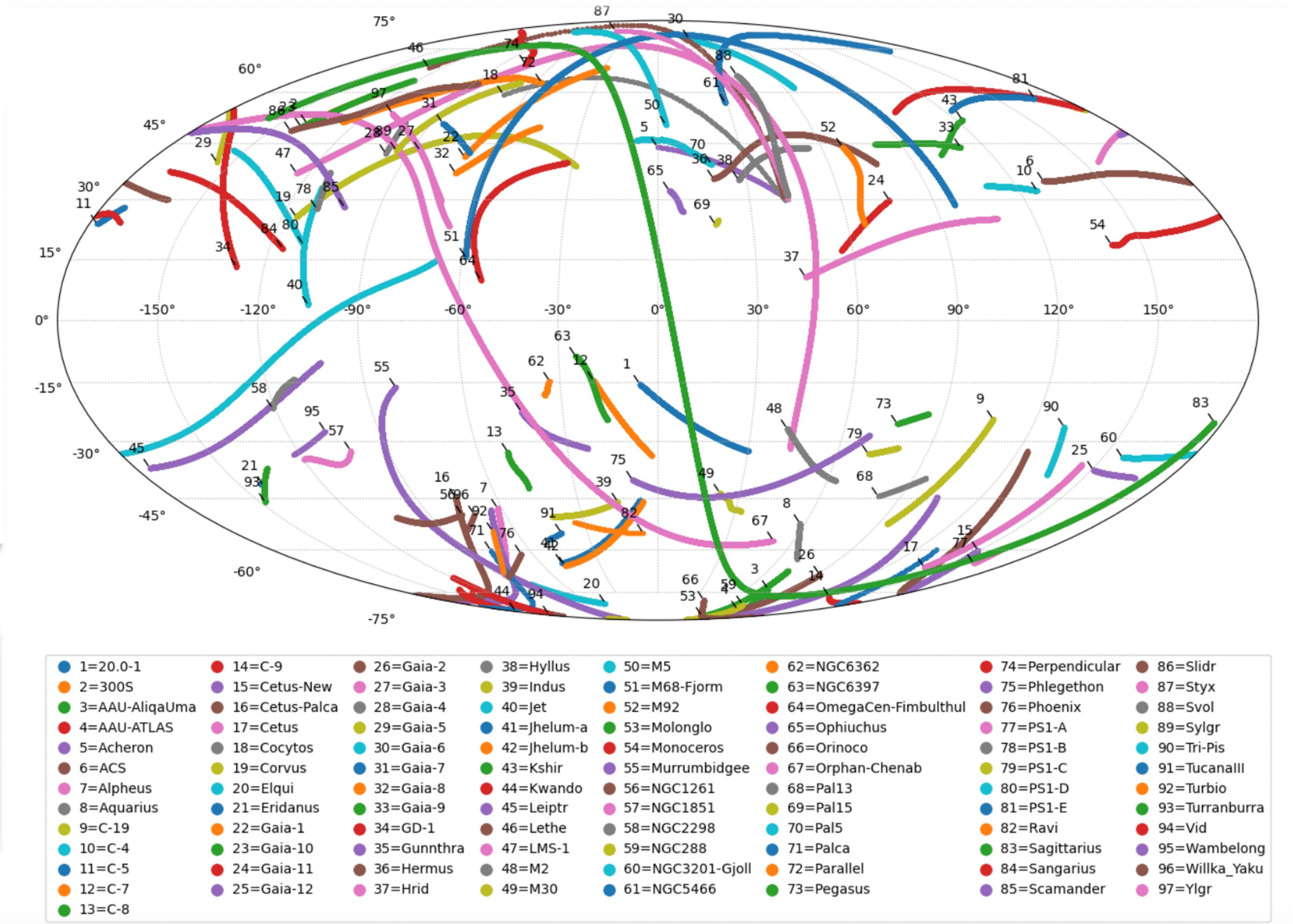
- Streams form as a result of the gravitational tidal force applied by the host Galaxy on the stream’s progenitor, which is a globular cluster (GC) or a dwarf galaxy (dG).

- A GC or a dG orbiting around the galaxy gets tidally stretched by the galactic potential, with the gravitational pull being harder on the closer stars to the galactic centre.

- The inner stars become a leading arm of the stellar stream while the outer stars form a trailing arm.

Known stellar streams (~ 100)

Observed by wide and deep sky surveys, such as SDSS, Pan-STARRS, Gaia and DESI.



Plot made with the Galstreams library (Mateu et al. 2018, Mateu 2023)

What can we learn from stellar streams?

1. Reconstructing the assembly history of the Milky Way

(e.g. Malhan et al. 2020)

2. Inferring the shape and mass of the Milky Way

(e.g. Malhan and Ibata 2021)

3. Dark matter subhalo searches

(e.g. Bonaca et. al 2019, Banik et. al 2021, McGee et al. 2022)

Subhalo searches with stellar streams

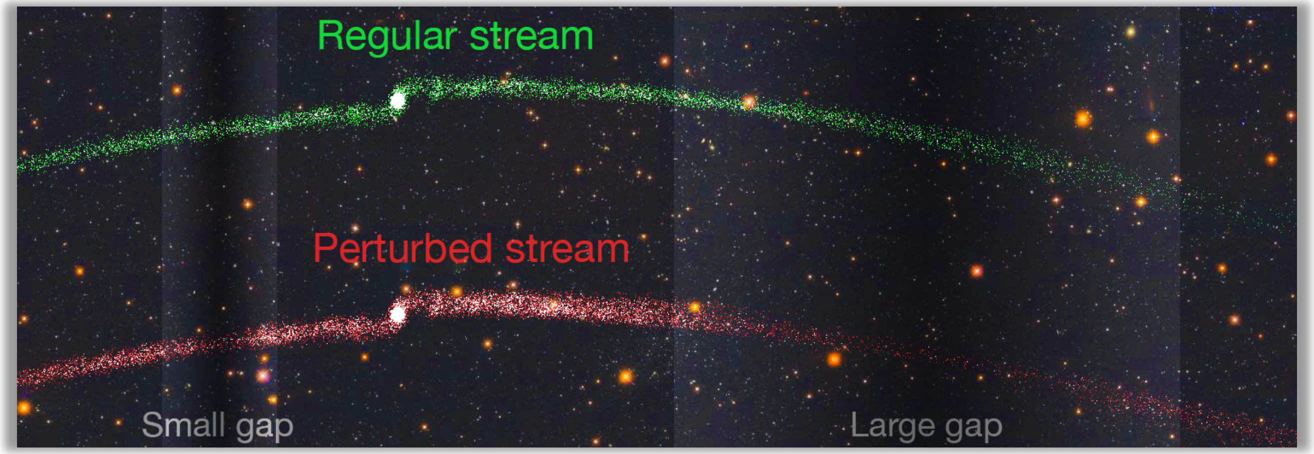
Perturbed streams

inhomogeneities in the density of stars

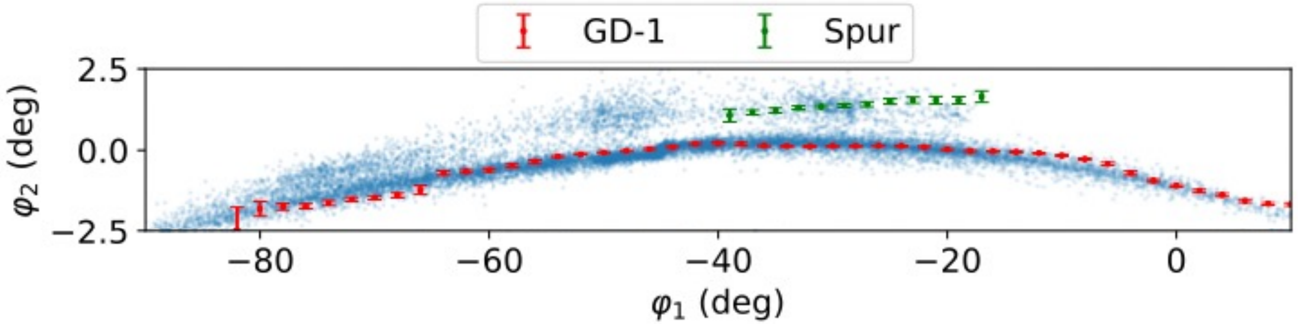
Gaps: Low concentration of stars

Blobs: Stars accumulation

Spurs: Linear groups of stars comoving with the main stream



Credit: V. Belokurov, D. Erkal, S.E. Koposov (IoA, Cambridge)



(T.J.L. de Boer et al. 2019)

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These inhomogeneities can be due to multiple effects
(it depends on the considered stream which one of these effects will be the dominant one):

- Orbital dynamics of the stars.
- Effects of the galactic gravitational potential (mainly by the effects of the disk, the bulge and the bar of the Milky Way).
- Impact of enough massive and close objects in the past, such as globular clusters or **DM subhalos**.

Subhalo searches with stellar streams

Several studies support the idea that anomalies in some streams could be due to an encounter with a DM subhalo (e.g. *Bonaca et. al 2019*, *Banik et. al 2021, McGee et al. 2022*) .

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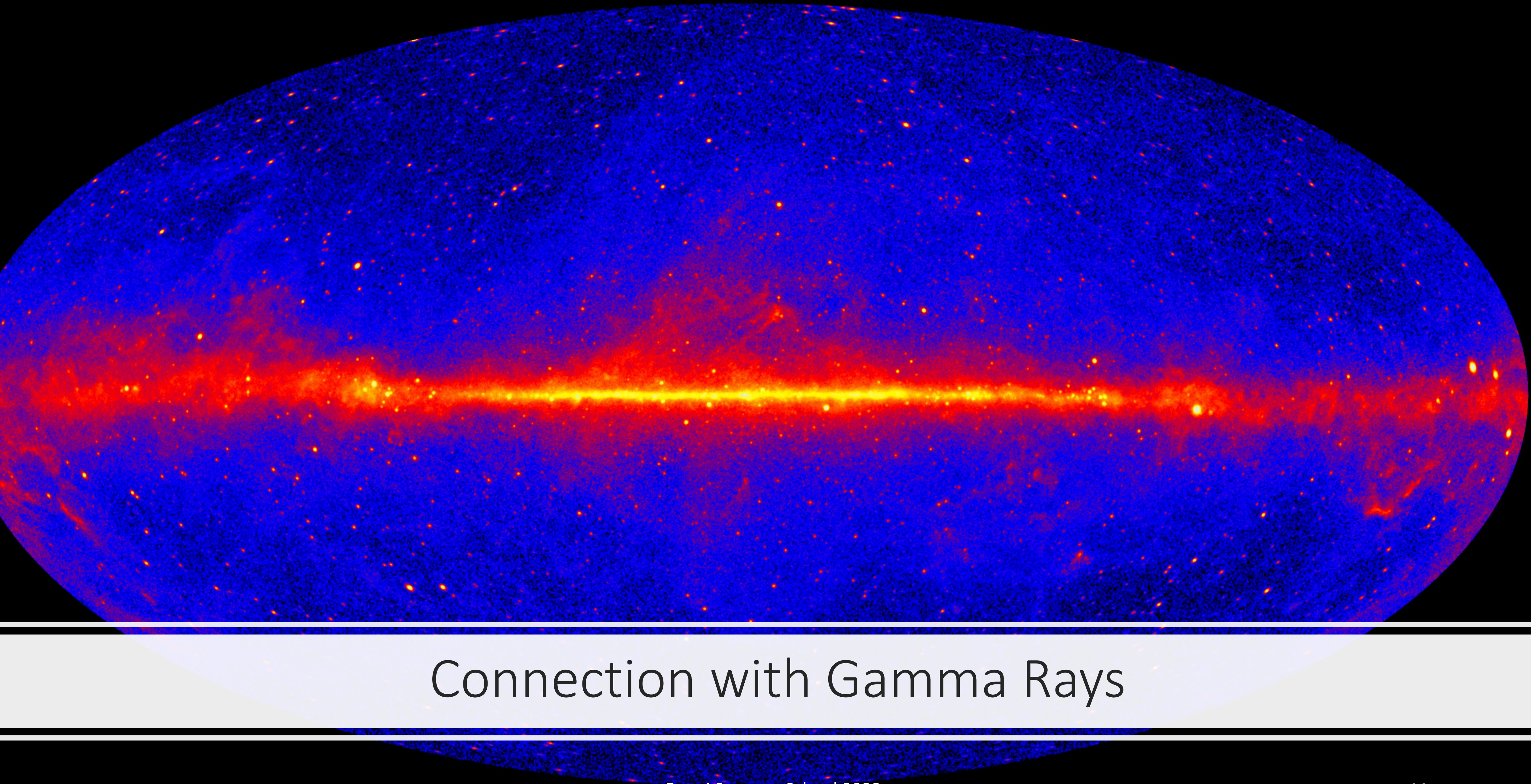


Connection with Gamma Rays

Connection with Gamma Rays

Novel point

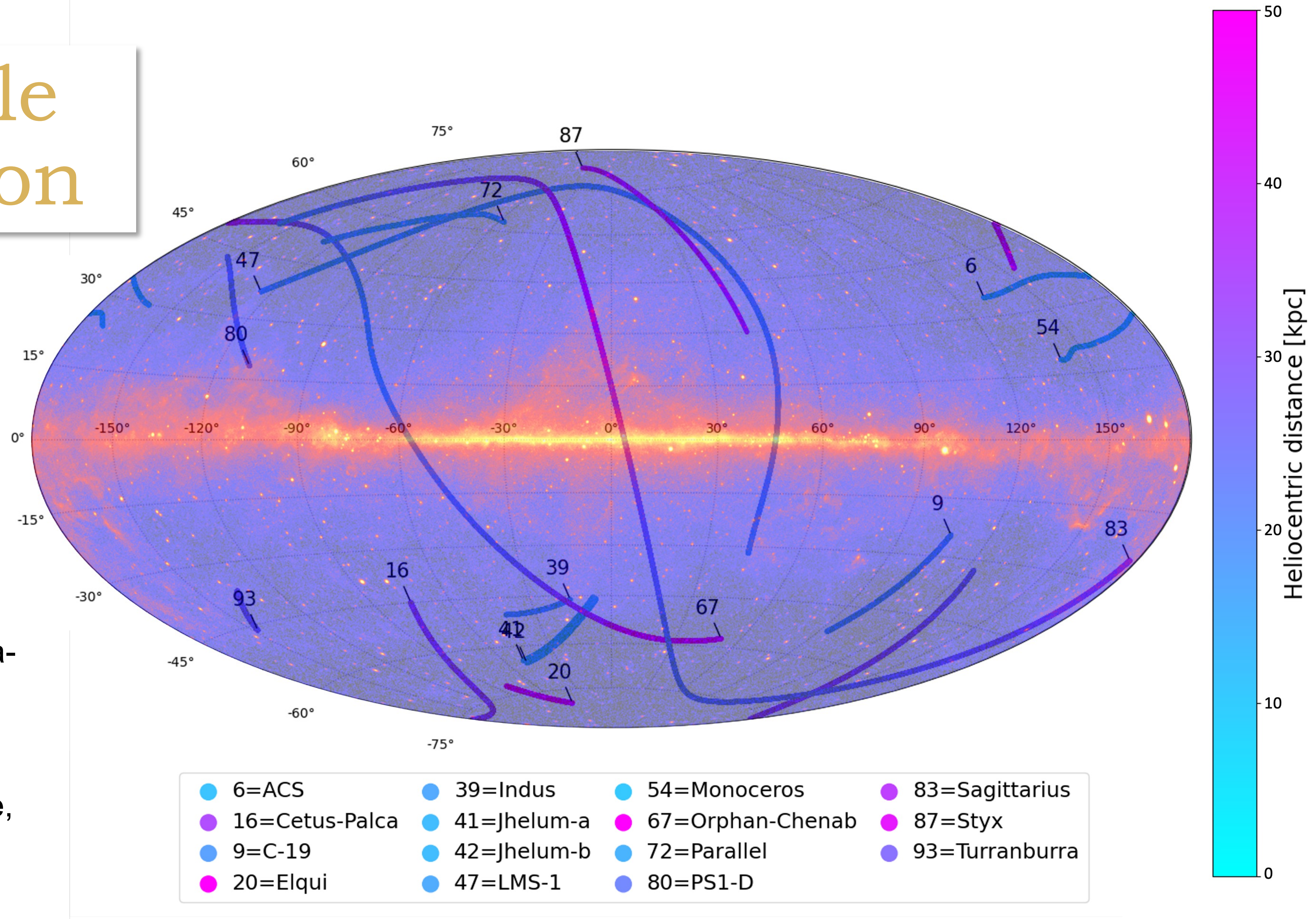
Explore the potential of considering stellar streams as a new tool for dark matter indirect searches with gamma rays

Assuming that the DM is in the form of WIMPs

As the **progenitor** of some streams can be a highly DM-dominated system, we can consider the stellar streams as our target and look for a potential annihilation signal in the form of gamma rays from the direction of the streams.

As the **perturbers** of some streams could be DM subhalos, we can investigate their possible current positions in the Galaxy and look for an annihilation signal from those sky regions.

Sample selection



① To build the best **sample of stellar streams** for gamma-ray DM searches, according to the most relevant properties (distance, DM content, etc.).

LAT analysis and DM modelling

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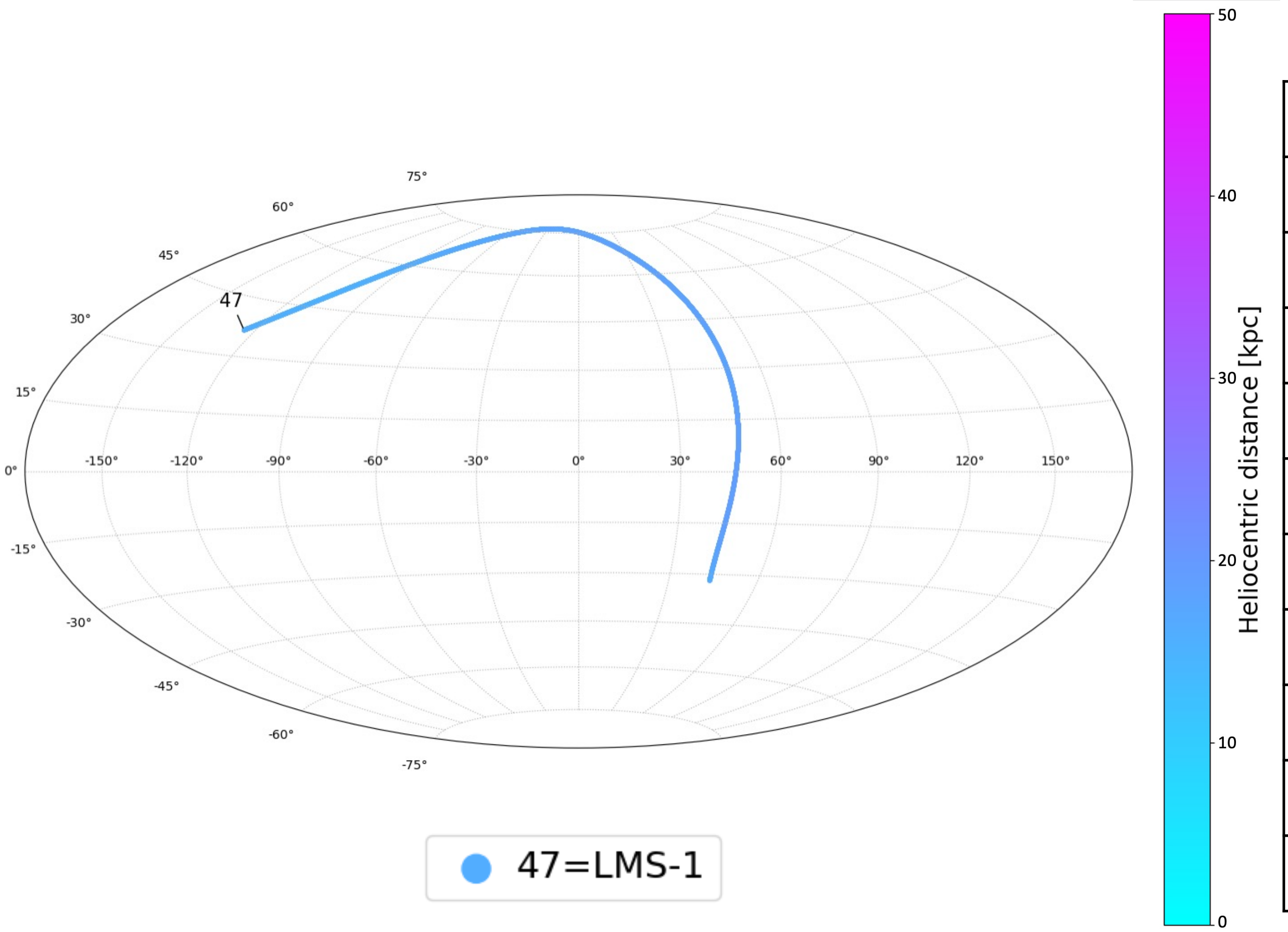
We will look for a potential **annihilation signal of WIMPs** in Fermi-LAT data from the direction of the best stellar streams in our sample.

We will also do the **DM modeling** of these streams, by making use of results from numerical cosmological simulations, with the goal of building their DM density profile and having a robust prediction of the DM annihilation gamma-ray flux from them.

With both the LAT analysis and the DM modeling, we will **set limits on the DM particle properties**.

Taking a first look…

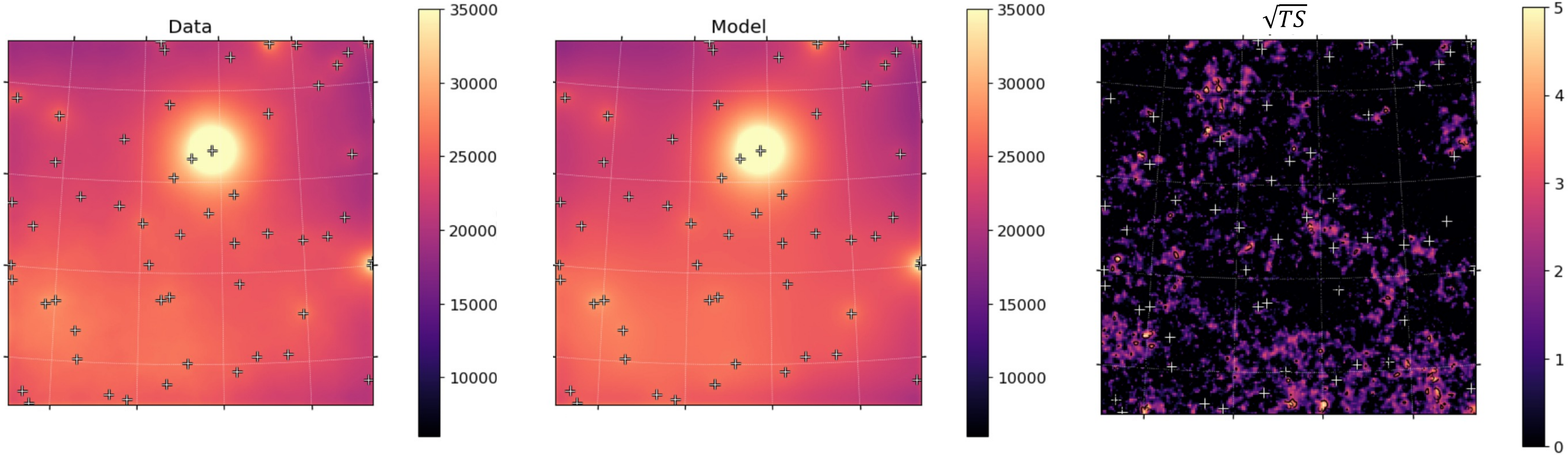


Spectral analysis technical setup

Time domain (Gregorian)	2008-08-04 to 2023-04-08
Time domain (MET)	239557417 to 702628118
Energy range	100 MeV – 200 GeV
IRF	P8R3_SOURCE_V3
Event type	FRONT + BACK
Point-source catalog	4FGL-DR3
ROI size	20º x 20º
Angular bin size	0.01º
Bins per energy decade	4
Galactic diffuse model	gll_iem_v07.fits
Isotropic diffuse model	iso_P8R3_SOURCE_V3_v1.txt

Taking a first look…

PRELIMINARY



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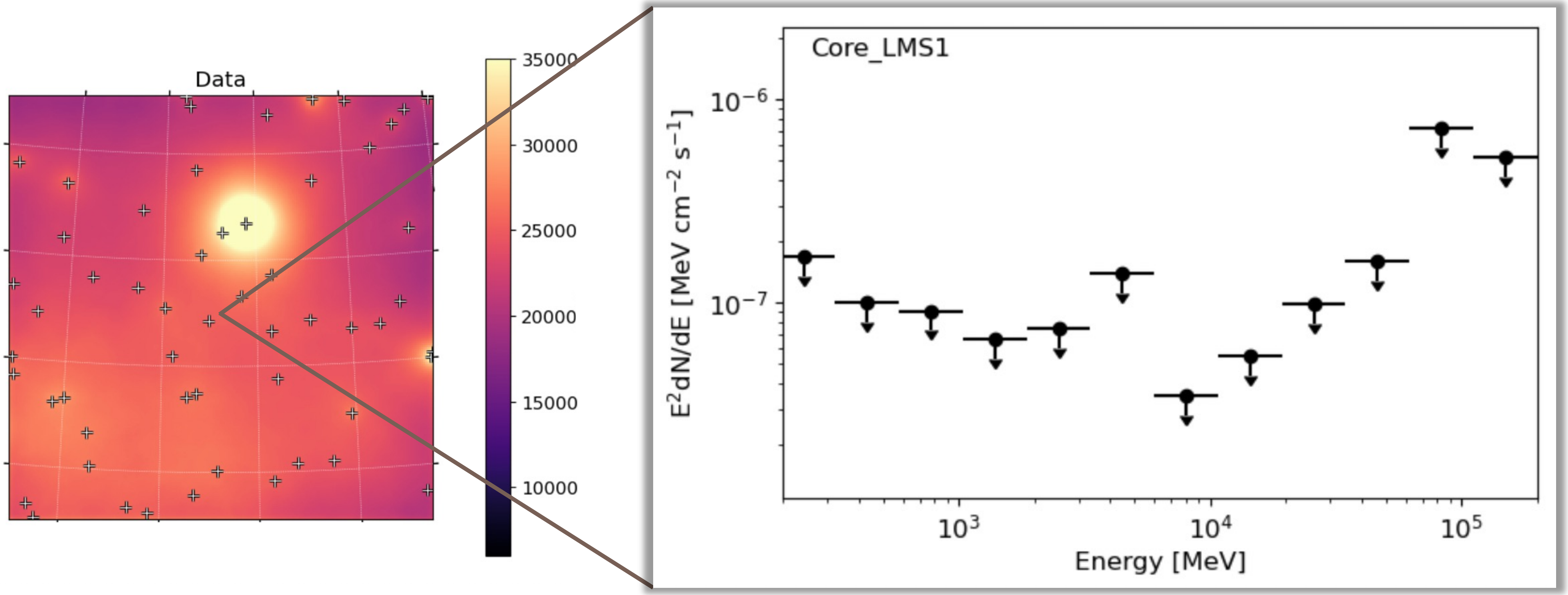
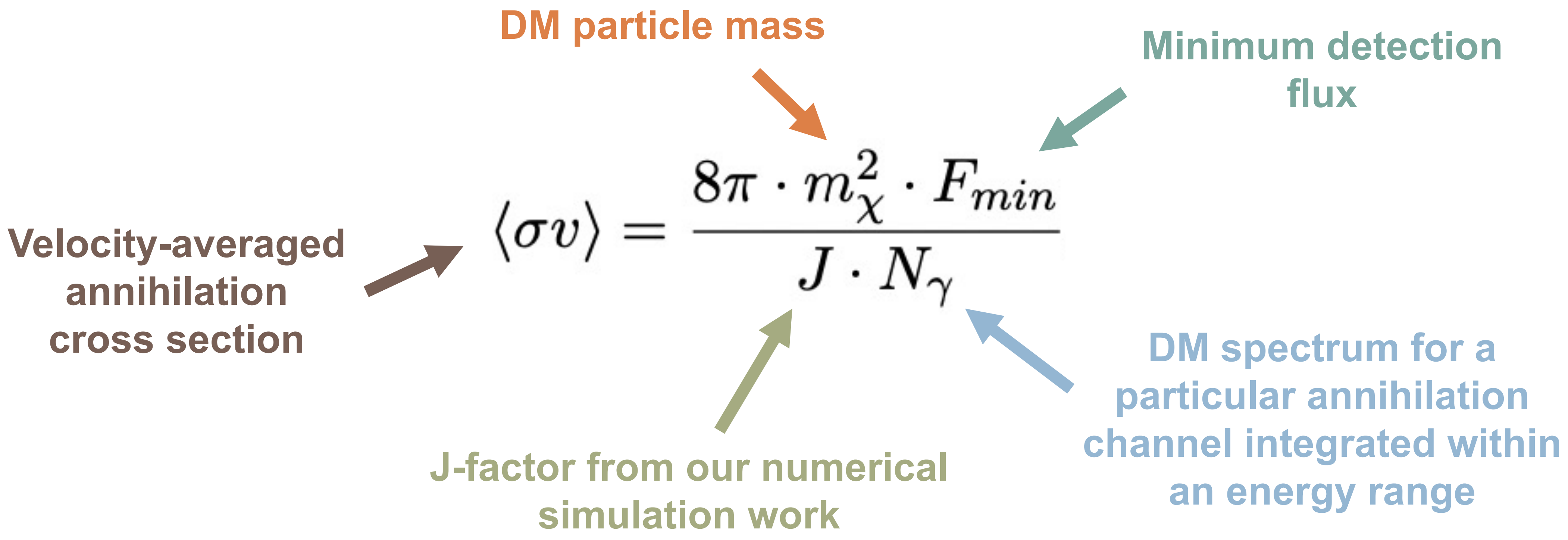


What’s next?

- In the absence of a signal, we will put constraints on the DM particle properties.



DM particle mass

Minimum detection flux

Velocity-averaged annihilation cross section

$$\langle \sigma v \rangle = \frac{8\pi \cdot m_{\chi}^{2} \cdot F_{min}}{J \cdot N_{\gamma}}$$

J-factor from our numerical simulation work

DM spectrum for a particular annihilation channel integrated within an energy range

General Remarks

Our main objective is to use stellar streams as a new tool to shed light on the properties of the DM particle.

This project will represent a *bridge* between the fields of stellar streams and gamma-ray DM searches, never crossed before.

Ongoing work: i) build the streams sample ii) first analysis with Fermipy iii) accurate DM modeling of the best streams.

Search of DM annihilation in Galactic Stellar Streams with the Fermi LAT

Thank you!

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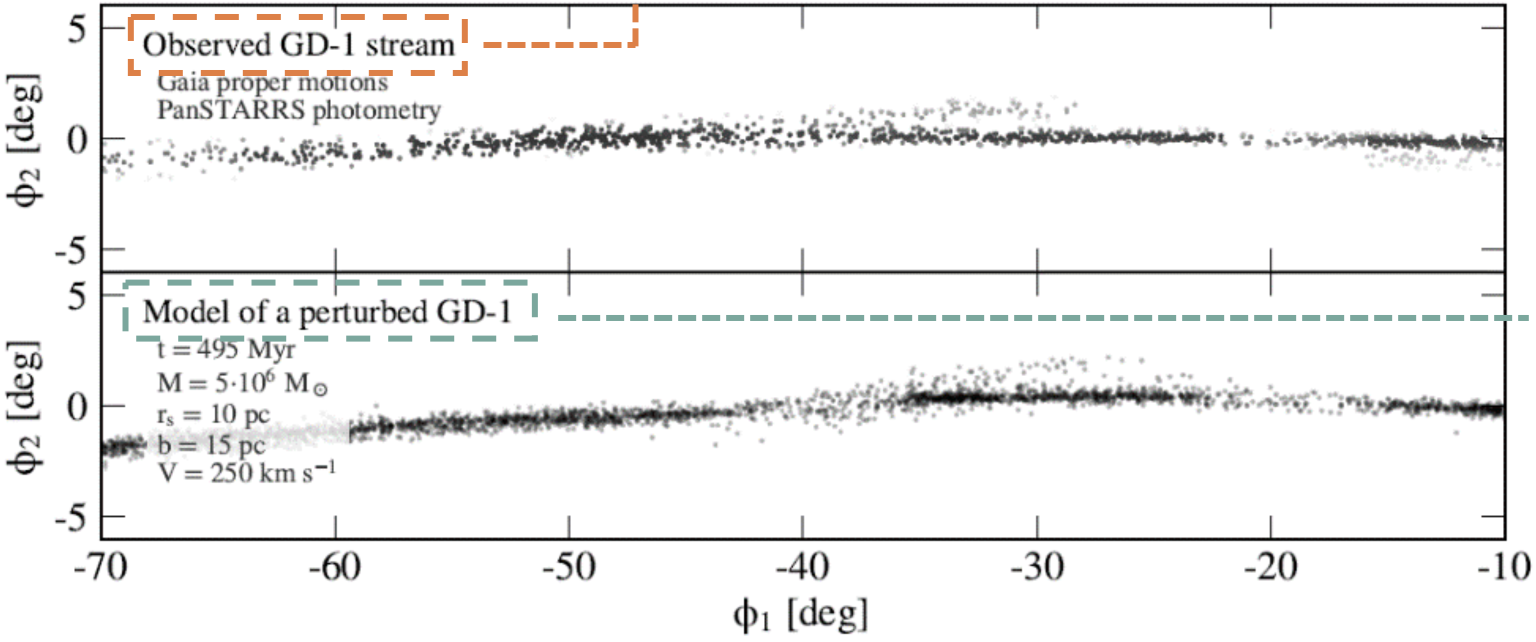
Supervisor: Miguel A. Sánchez-Conde

Backup slides

Subhalo searches with stellar streams

- Simulations show that the crossing of massive objects would induce gaps in the stream, being the gap size proportional to the mass of the impacting object.

Two significant gaps located at -20º and -40º



(Bonaca et al., 2019)

Simulation assuming:

The **progenitor** was disrupted at -20º, to produce the gap at - 20º.

The stream has been recently perturbed by a compact, massive object (the **perturber**) on an orbit that crosses GD-1. As a consequence of this encounter, the gap at -40º would be produced.

They claim that the most likely explanation for this gap and for the spur of GD-1 is an encounter with a DM substructure in the mass range of $10^6 - 10^8\ M_\odot$.

Subhalo searches with stellar streams

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  Several studies (e.g. *Bonaca et. al 2019*, *Banik et. al 2021, McGee et al. 2022*) support the idea that the anomalies in the GD-1 stream could be due to an encounter with a DM subhalo. Moreover, there are some studies searching for the posible present-day sky positions of the perturber of the GD-1 stream (*Bonaca et al. 2020*, *Mirabal et al. 2021*).

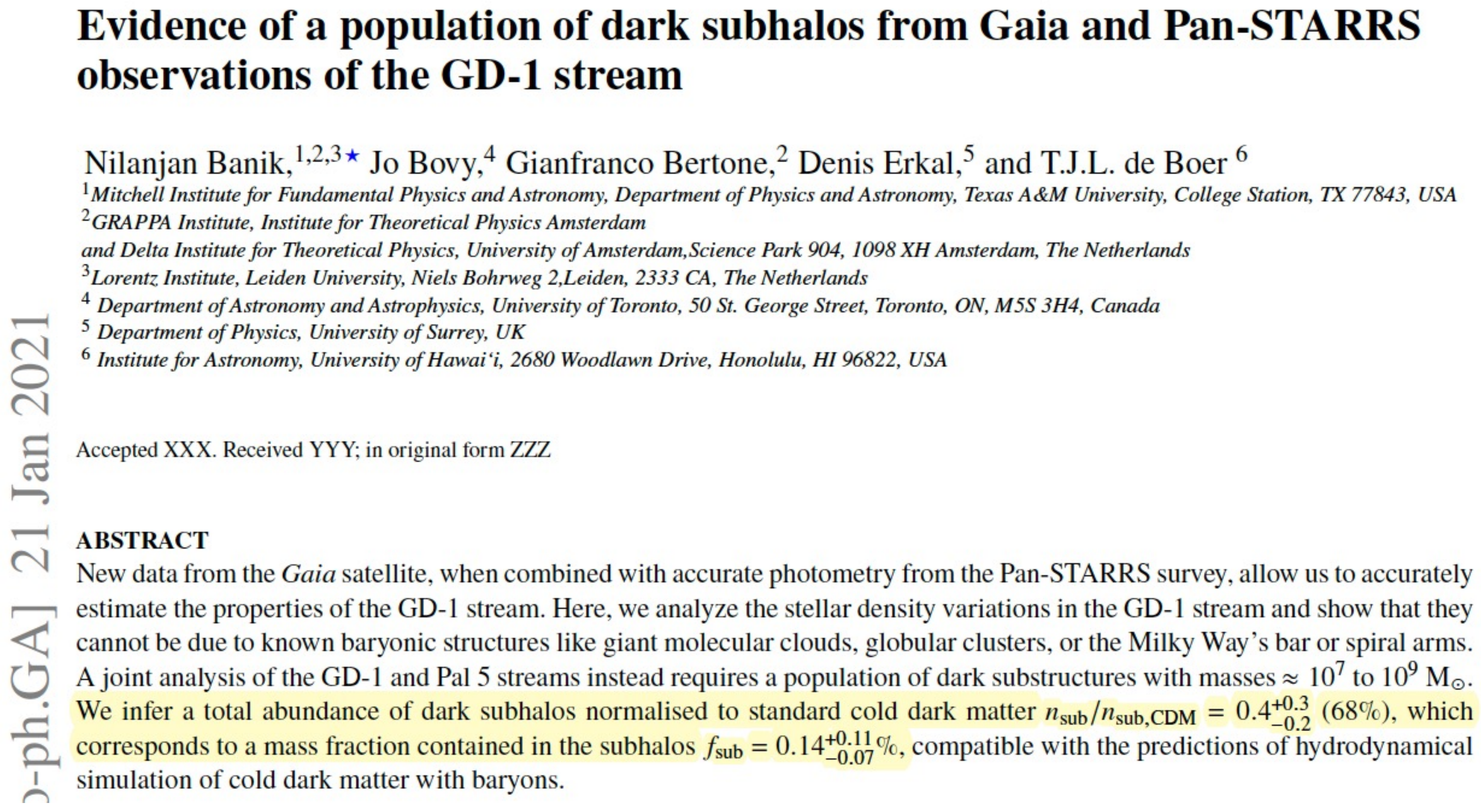
- The number of encounters with DM subhalos would be proportional to the number density of them along the stream's orbit.

If we have enough data, the number and properties of stream gaps found in the streams should be in agreement with that expected from a ΛCDM subhalo population in the Galaxy.

Subhalo searches with stellar streams

If we had enough data, the number of stream gaps found in the streams and their sizes should be in agreement with that expected from a ΛCDM subhalo population in the Galaxy.

Banik et. al 2021 show that the power spectrum of *GD-1* stream can be explained not only by the influence of the baryonic galactic structures, but by adding the perturbation of DM subhalo impacts.



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Evidence of a population of dark subhalos from Gaia and Pan-STARRS observations of the GD-1 stream

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ABSTRACT

New data from the *Gaia* satellite, when combined with accurate photometry from the Pan-STARRS survey, allow us to accurately estimate the properties of the GD-1 stream. Here, we analyze the stellar density variations in the GD-1 stream and show that they cannot be due to known baryonic structures like giant molecular clouds, globular clusters, or the Milky Way's bar or spiral arms. A joint analysis of the GD-1 and Pal 5 streams instead requires a population of dark substructures with masses ≈ 10^7 to 10^9 $M_\odot$. We infer a total abundance of dark subhalos normalised to standard cold dark matter $n_{\rm sub}/n_{\rm sub,CDM} = 0.4^{+0.3}_{-0.2}$ (68%), which corresponds to a mass fraction contained in the subhalos $f_{\rm sub} = 0.14^{+0.11}_{-0.07}\%$, compatible with the predictions of hydrodynamical simulation of cold dark matter with baryons.